

## 4. Visibility Conditions in National Parks

The following discussion is based on published papers and reports or on ongoing analyses of non-urban particle data collected by the Interagency Monitoring of Protected Visual Environments (IMPROVE) program and the Clean Air Status and Trends Network (CASTNet). Citations to the open literature or manuscripts are provided for referenced publications, and where possible, copies of ongoing work and work to be submitted for publication are also provided. Additional related references not explicitly cited herein are also provided in the Reference list.

### **Spatial and Seasonal Visibility:**

The pollutants responsible for current visibility impairment are well documented. Visibility observations taken over the last 50-years in the Southeastern U.S., suggest that visibility has decreased by 80% in summer and by 40% in winter. Spatial and seasonal variations in aerosol composition and concentrations contributing to visibility impairment have been examined (Malm, et al., 2000). These analyses have shown that:

- 1) Visibility impairment is mostly due to fine particles.
- 2) Average fine particle concentrations are much higher than estimates of natural conditions (Trijonis et al., 1990).
- 3) Aerosol concentrations are much higher in the Eastern U.S. than in the Western U.S..
- 4) Visibility impairment due to aerosol is much higher in the Eastern U.S. than in the Western U.S.
- 5) In general, the visibility impairment due to aerosol is greatest in the summer, although the seasonal difference is not as pronounced in the Western U.S.
- 6) In the Eastern U.S., sulfate compounds are the dominant cause of visibility impairment, due to aerosol. In the Western U.S., organic material and soil can be as important as sulfate. In central and southern California, ammonium nitrate can also be a major contributor to visibility impairment. Nitrate is also important episodically at a number of locations, particularly in winter months.

Figures 1a through 1c provide examples of the average conditions described above. In the case of Shenandoah and Great Smoky Mountains NPs in the East, the average visibility impairment ranges from about  $40 \text{ Mm}^{-1}$  in winter to  $180 \text{ Mm}^{-1}$  in summer. However, at Rocky Mountain NP it varies from about 5 to  $20 \text{ Mm}^{-1}$ , with the summer generally having the greatest aerosol impairment. The difference is not as pronounced in Rocky Mountain NP, and the fractional contribution of other constituents, particularly organic material, is greater at Rocky Mountain NP.

Figures 2 through 4 provide a portrayal of the chemical makeup of the aerosol as a function of the amount of particulate matter in the air. At Shenandoah and Great Smoky Mountains NPs, the frequency distributions of the fine particle mass and the major constituents show that sulfate particles are a larger fraction of the fine mass when the concentration is high than when the concentration is low. The largest fraction of the fine mass at Rocky Mountain NP at all concentration levels is carbonaceous material. Also, at Rocky Mountain NP, the fraction of fine mass due to nitrates rises as the fine mass concentration rises.

**Temporal Variations:**

With the emission reduction mandated by Title IV of the Clean Air Act and with the promulgation of the Regional Haze Rule, temporal trends are/will be of great interest. Analyses of 10-year trends (1988-1997 and 1989-1998) of the haziest visibility conditions at existing IMPROVE monitoring locations are shown in Figures 5a and 5b.

Conditions at a number of sites appear to be degrading, including 3 sites in the east. Consider the results of a regional analysis performed on the sulfate data collected at CASTNet monitoring sites (Figure 6). The graph at the left shows four regions of the Eastern U.S. defined by the similar variation of the sulfate concentrations within each region. This is based on analysis of spatial and temporal trends called empirical orthogonal functions. The graph on the right shows the temporal trends in sulfate concentrations for each of the four regions. Regions 1 and 3 in the Northeast and Midwest show decreases in sulfate concentrations, Region 2 shows little trend, and Region 4, farthest to the Southeast, shows an increase in concentration.

Similar spatial/temporal analyses, using IMPROVE and CASTNet data, Figures 7a and 7b, display an interesting pattern and suggest additional analyses and comparison with emissions trends. Figure 7a shows the contours of the 90<sup>th</sup> percentile of the summertime sulfate concentrations for the years 1991-1995. Figure 7b shows the contours of the 90<sup>th</sup> percentile of the summertime sulfate concentrations for the years 1995-1999. In the Eastern U.S., the location of the highest concentrations appears to have grown smaller and moved southward, while the magnitude of the highest concentrations has stayed about the same. Similar patterns were observed during the spring and fall. These plots also show the strong differential in sulfate concentrations between the east and the west. This pattern also occurs in plots of the median sulfate concentrations (not shown). Figures 8a and 8b show the spatial pattern for the 90<sup>th</sup> percentile for ammonium nitrate for 1991-1995 and 1995-1999, respectively. The highest concentrations are in the Midwest, with local maxima in California, Alabama and the Chesapeake Bay area. Spatial patterns are similar for both time periods. (Note that the local maxima Eastern Oregon and northern Utah can not be temporally compared since the monitors were not in place during both time periods.) Spatial patterns for the median are similar (not shown).

Analyses of the temporal trends at the three parks and Brigantine Wilderness, within the E. B. Forsythe National Wildlife Refuge, are shown in Figures 9a through 9d. The long-term statistically significant trend ( $p=0.05$ ) degrading trend over the 1989-1998 time period of poor visibility at Great Smoky Mountains NP is evident (Figure 10). A similar degrading trend is evident at Brigantine Wilderness and Shenandoah NP but at significance levels over 0.15. Rocky Mountain NP shows an improving trend ( $p=0.15$ ).

**Identification of Source Regions:**

In order to gain some insight into the geographic regions that may be contributing to the visibility impairment at the three National Parks discussed above, the results of two additional analyses are presented in Figures 11a through 11c and 12a through 12c. The maps in Figure 11 show the probability that if an air mass passed over an area enroute to a park it arrived at the park when the measured, weather-filtered visibility was in the worst 10% of measurements made there

during the summer months. These months have the worst monthly-mean visibility. Examining a single season helps avoid confounding the results with seasonal differences in transport patterns. Note that results in individual grid cells are not as meaningful as looking at entire pathways associated with poor visibility. Note also, that this analysis does not show how often air masses arrived from any given area, only the probability that if they did arrive from there, there was extremely poor visibility at the park. The results for each park are:

- Shenandoah NP – Air masses arriving from areas along the Ohio River or from the Louisiana, Arkansas, Mississippi area are most often associated with the highest extinction during the months with the poorest visibility.
- Great Smoky Mountains NP – Air masses arriving from a corridor east of the park extending through western North Carolina, West Virginia, eastern Ohio and western Pennsylvania and curving around the Great Lakes have the highest probability of arriving when the extinction is extremely high during June-September. Another pathway extends from the park through northern Alabama and along the Alabama-Mississippi border.
- Rocky Mountain NP – During the summer months, air masses arriving from the front range of Colorado have the highest probability of arriving when the extinction is extremely high.

The maps in Figure 12 show the areas that air masses most often arrived from when the measured, weather-filtered visibility at the three National Parks was in the worst 10% of measurements made there during the summer months. The values plotted are the amount of time the air mass spent in the area divided by the amount of time that would have been expected if air masses arrived from all directions with equal probability. The higher the value, the more often air masses arrived from that area when the visibility was poorest at the park. The results for each park are:

- Shenandoah NP – The measured visibility was in the worst 10%, when air masses most often arrived at the park from the west and especially from the Ohio River Valley areas of southern Ohio, Indiana, and Illinois and also the St. Louis area.
- Great Smoky Mountains NP – When the measured visibility was in the worst 10%, air masses most often arrived at the park from an area running from the northern Alabama-Mississippi border to the St. Louis area, or from a region stretching roughly from due east of the park up through eastern Ohio.
- Rocky Mountain NP – When the visibility was in the worst 10%, air masses most often arrived at the park from the northwest and southwest.

The figures only provide an indication of the transport directions that correspond to episodes with high visibility impairment. They do not establish any source-receptor relationships. Selection of transport layers and stratification of the data sets to represent other visibility conditions could lead to slightly different results. Selection of other time periods or seasons could modify the patterns. The patterns might not be representative of the effect of local/nearby sources.

## References

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Figure 1a. Monthly Contributions to Extinction – Shenandoah NP

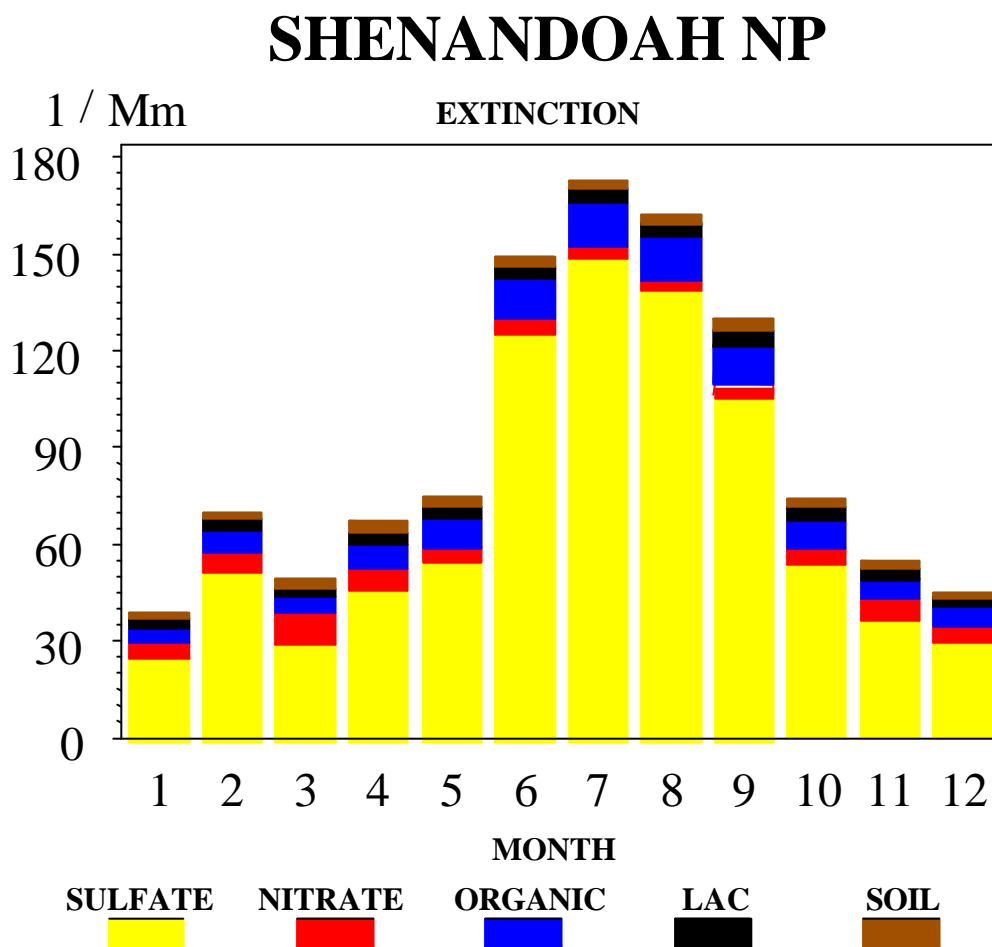


Figure 1b. Monthly Contributions to Extinction – Great Smoky Mountains NP

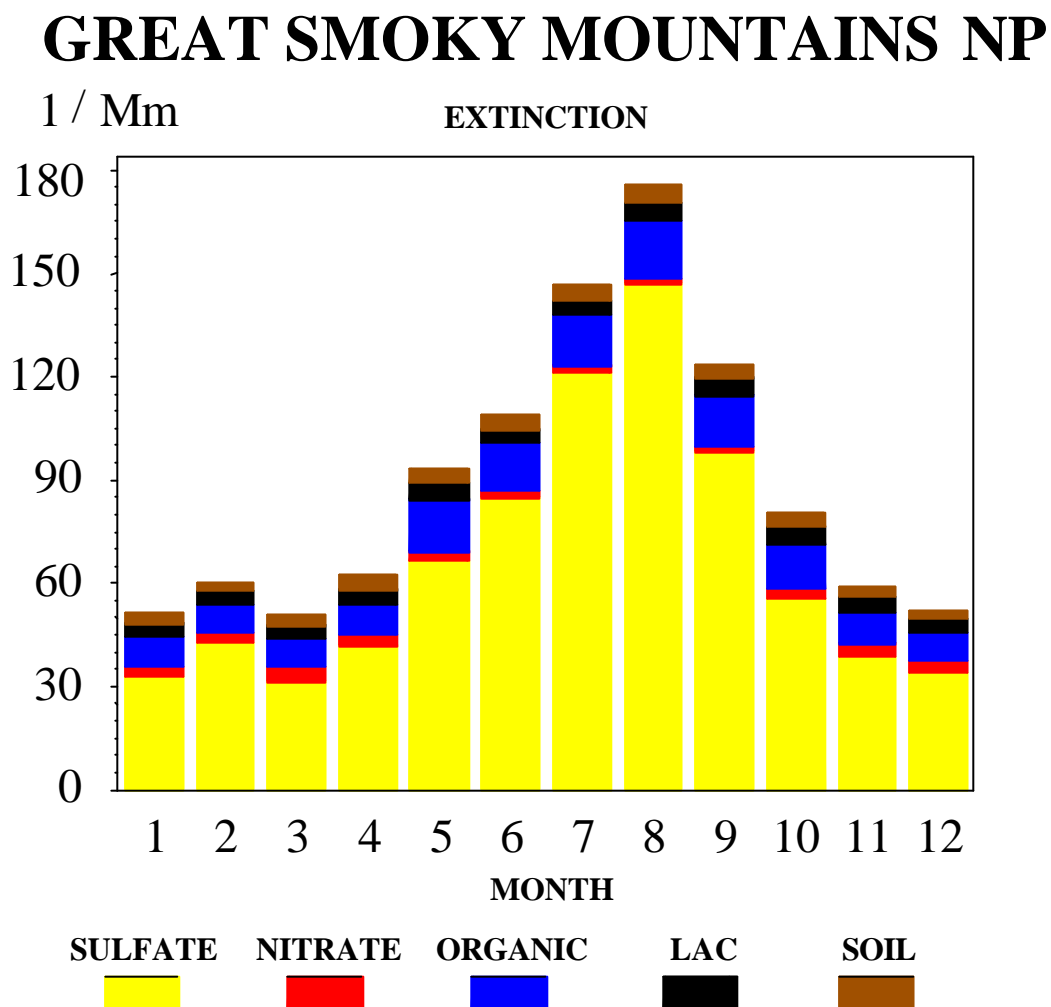




Figure 1c. Monthly Contributions to Extinction -- Rocky Mountain NP

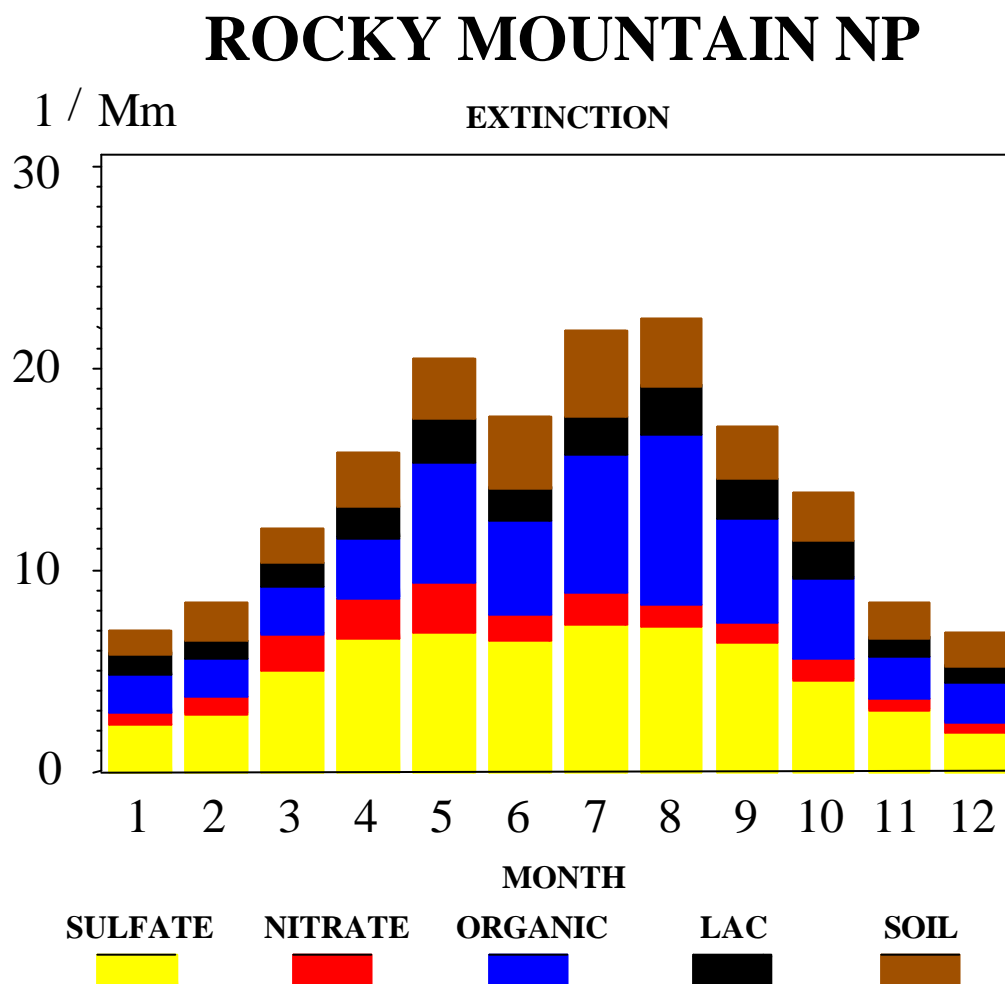


Figure 2. Annual Species Frequency Distribution (a) and Reconstructed Fine Mass (RCFM) Fraction (b) for Shenandoah NP.

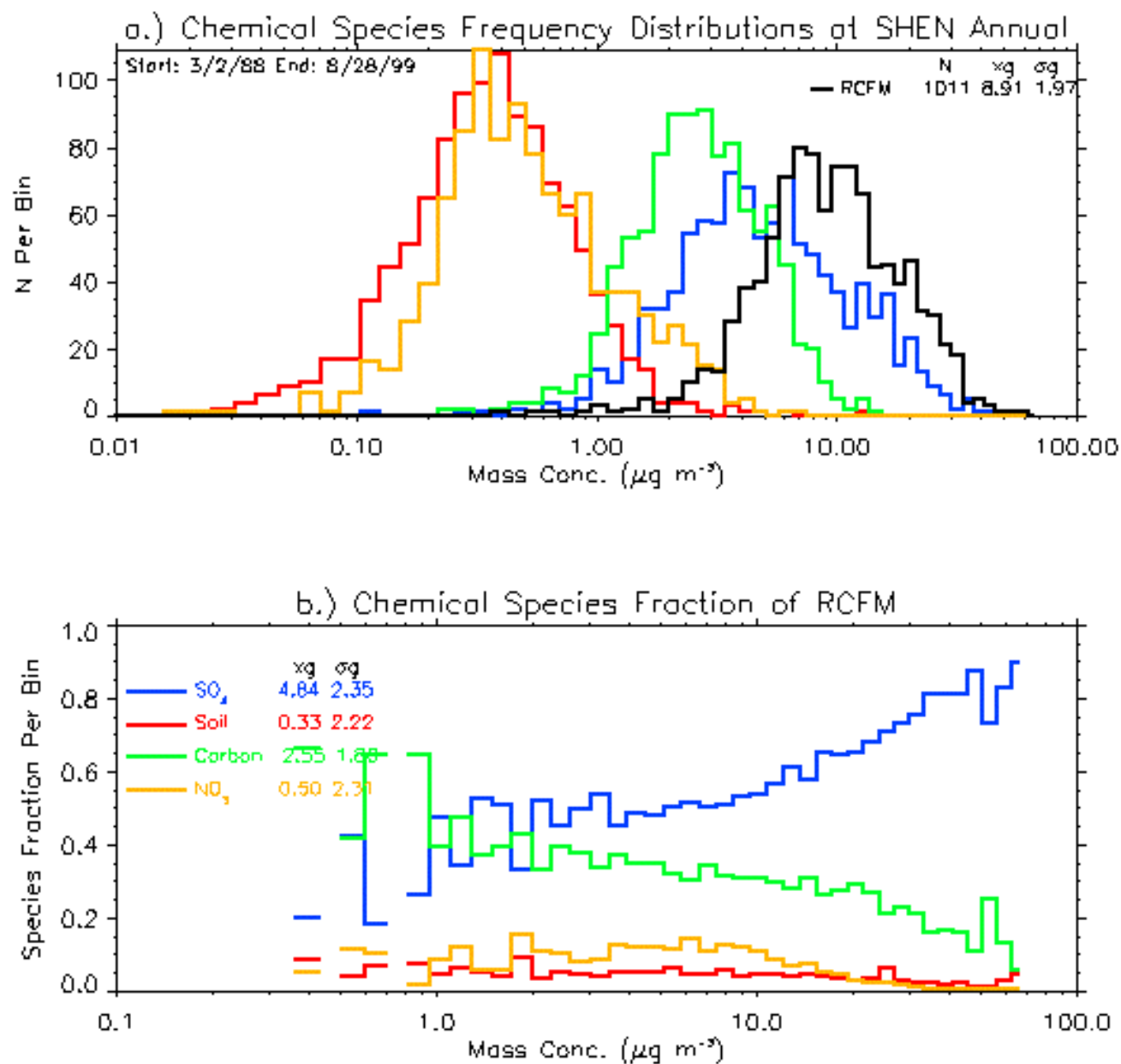


Figure 3. Annual Species Frequency Distribution (a) and Reconstructed Fine Mass (RCFM) Fraction (b) for Great Smoky Mountain NP.

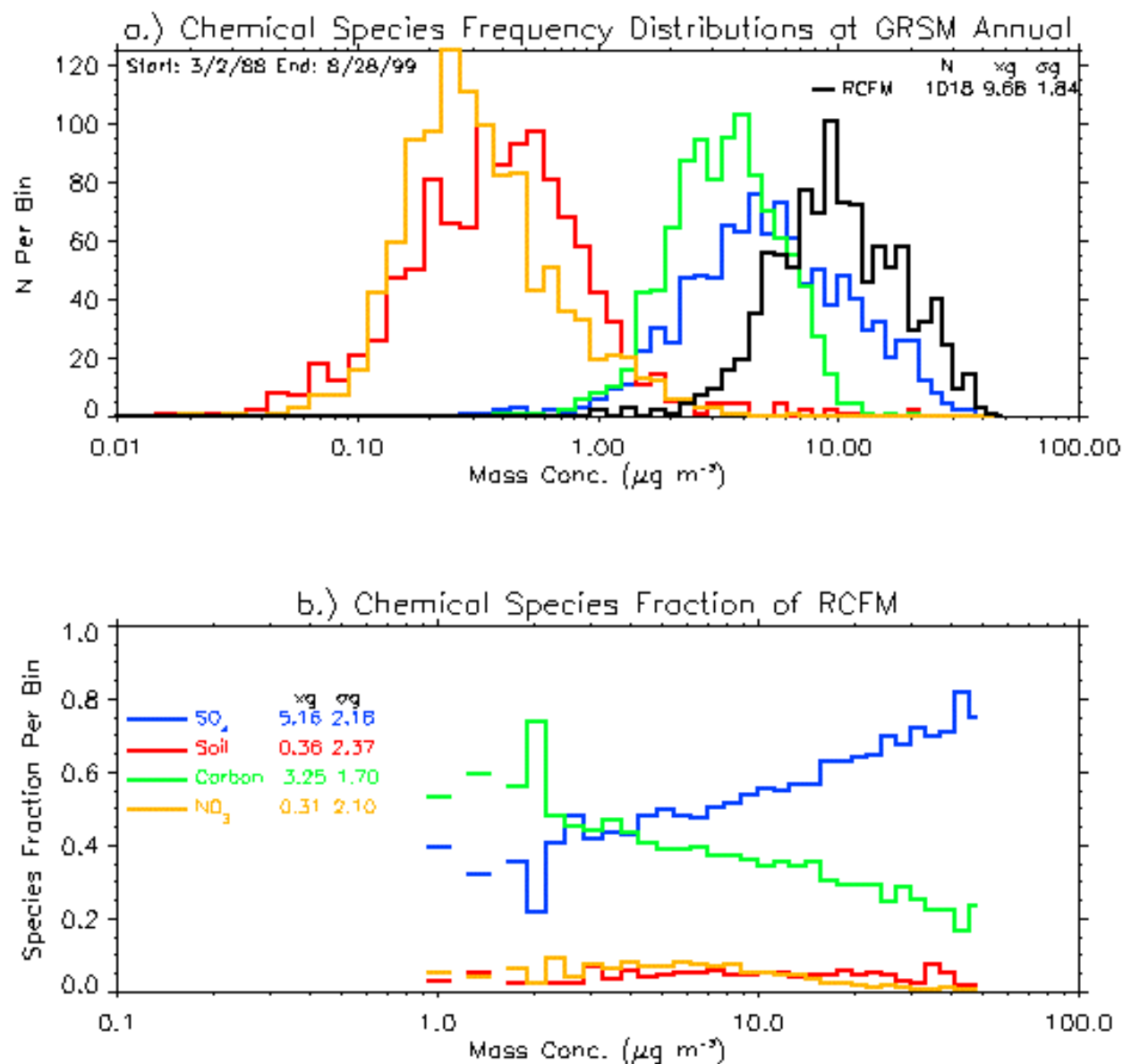
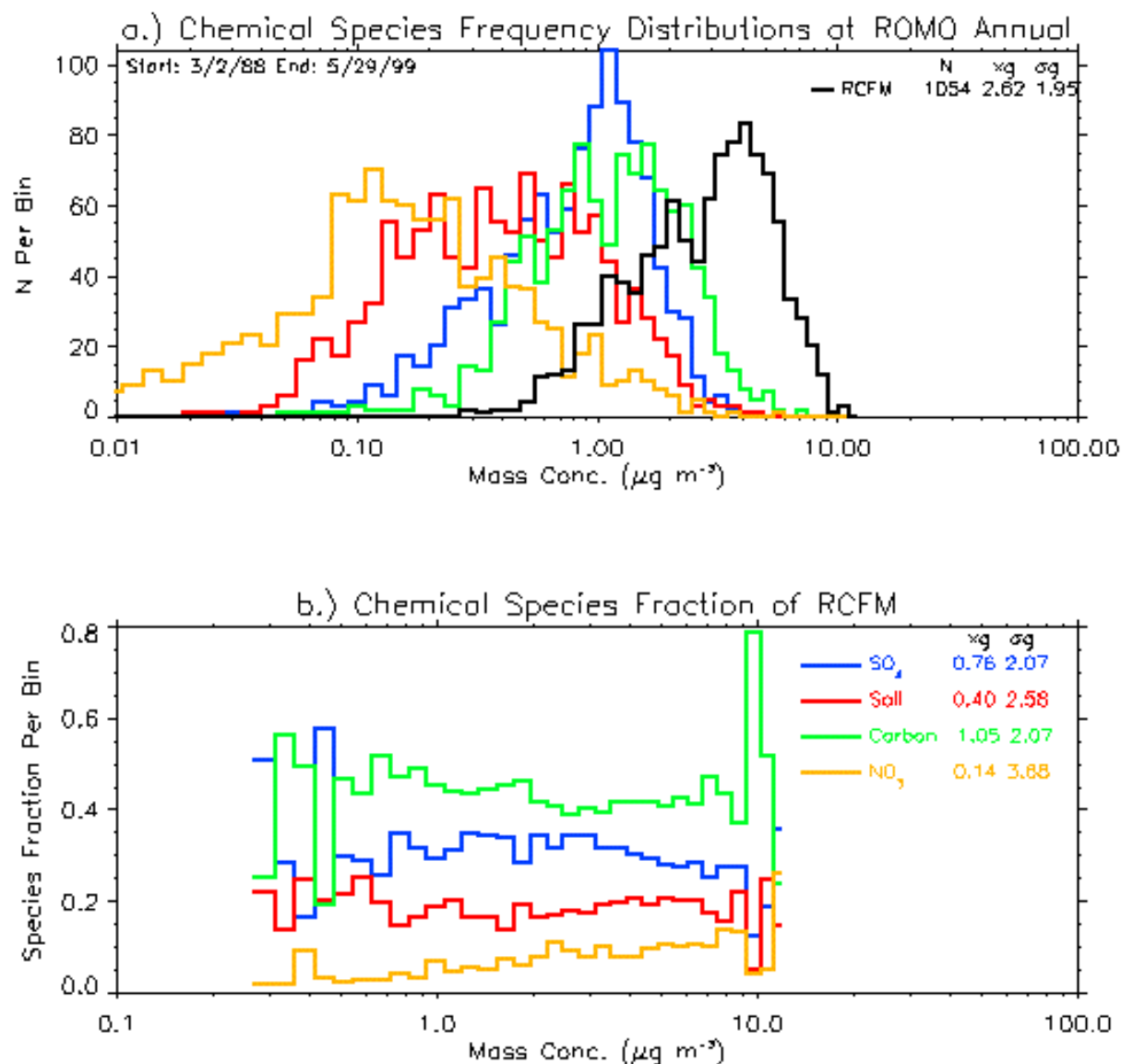
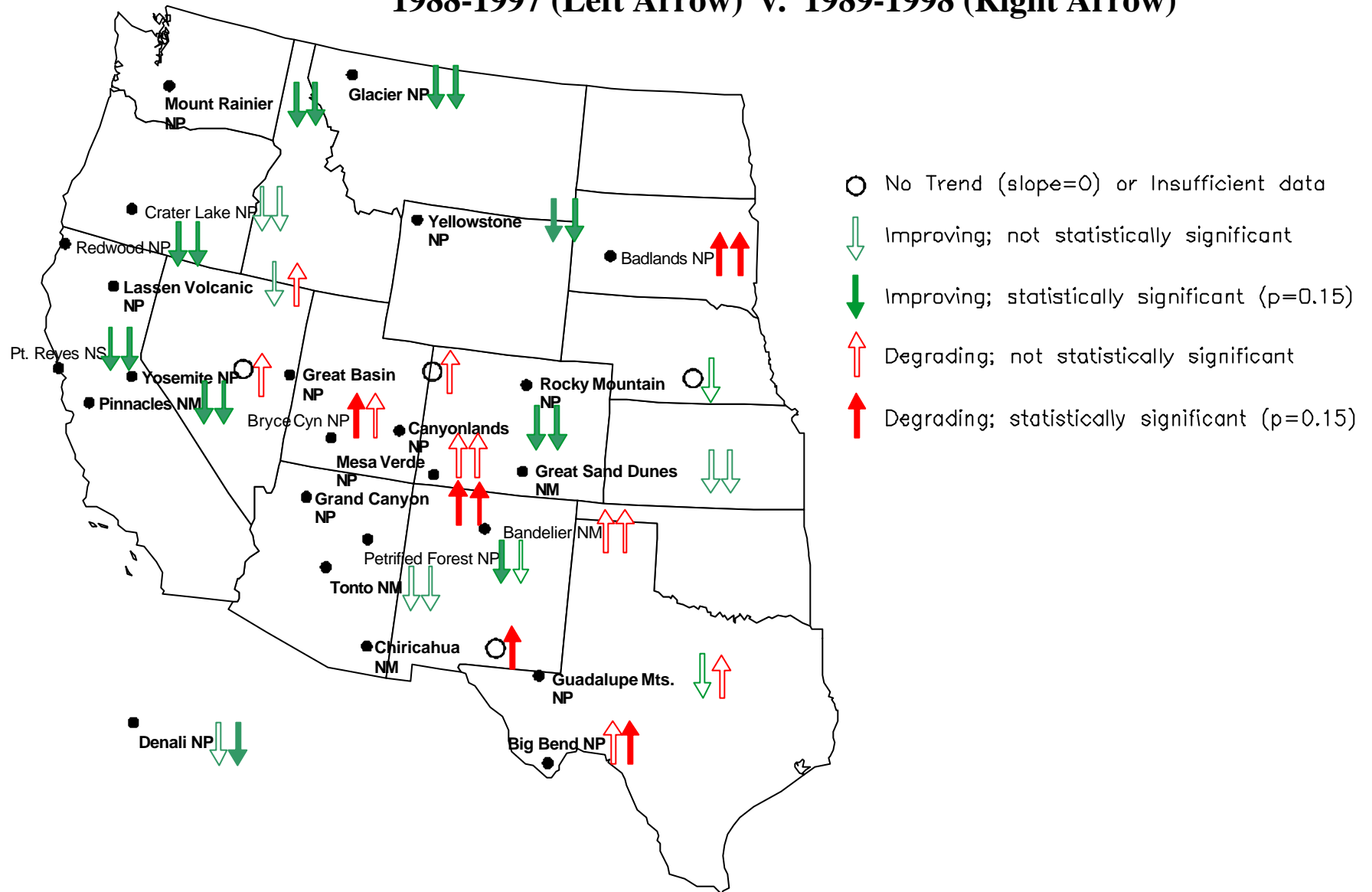
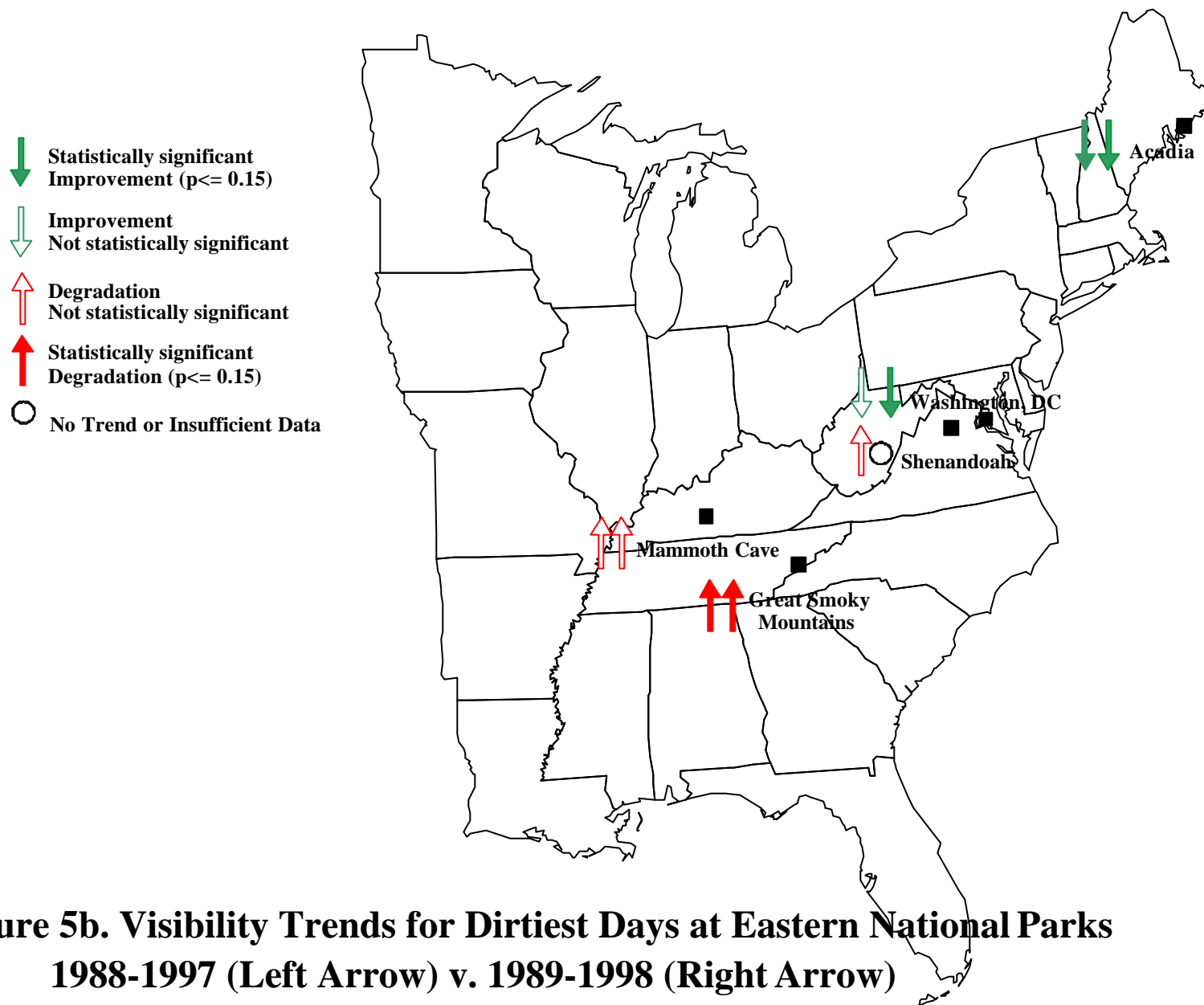


Figure 4. Annual Species Frequency Distribution (a) and Reconstructed Fine Mass (RCFM) Fraction (b) for Rocky Mountain NP.



**Figure 5a. Visibility Trends for Haziest Days in Western National Parks  
1988-1997 (Left Arrow) v. 1989-1998 (Right Arrow)**





**Figure 5b. Visibility Trends for Dirtiest Days at Eastern National Parks 1988-1997 (Left Arrow) v. 1989-1998 (Right Arrow)**

(Dirtiest days defined as the mean, in deciviews, of the 20% dirtiest days during year.)

Figure 6. Sulfate Trends at Eastern CASTNET Sites.

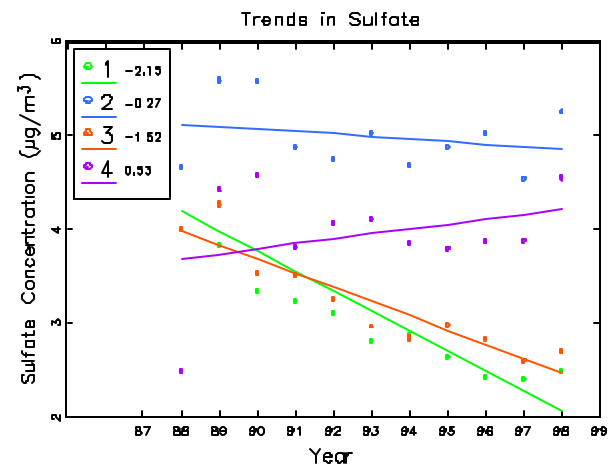
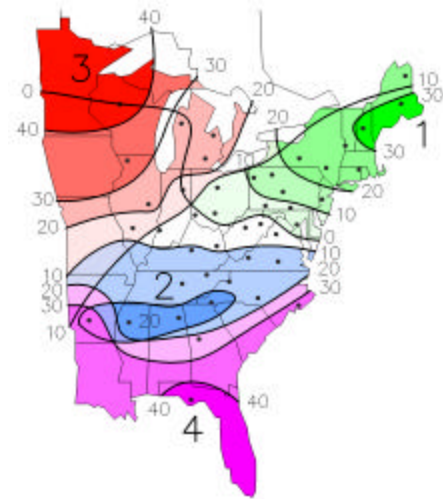


Figure 7a. High Summertime Ammonium Sulfate Concentrations ( $\mu\text{g}/\text{m}^3$ )  
1991-1995.

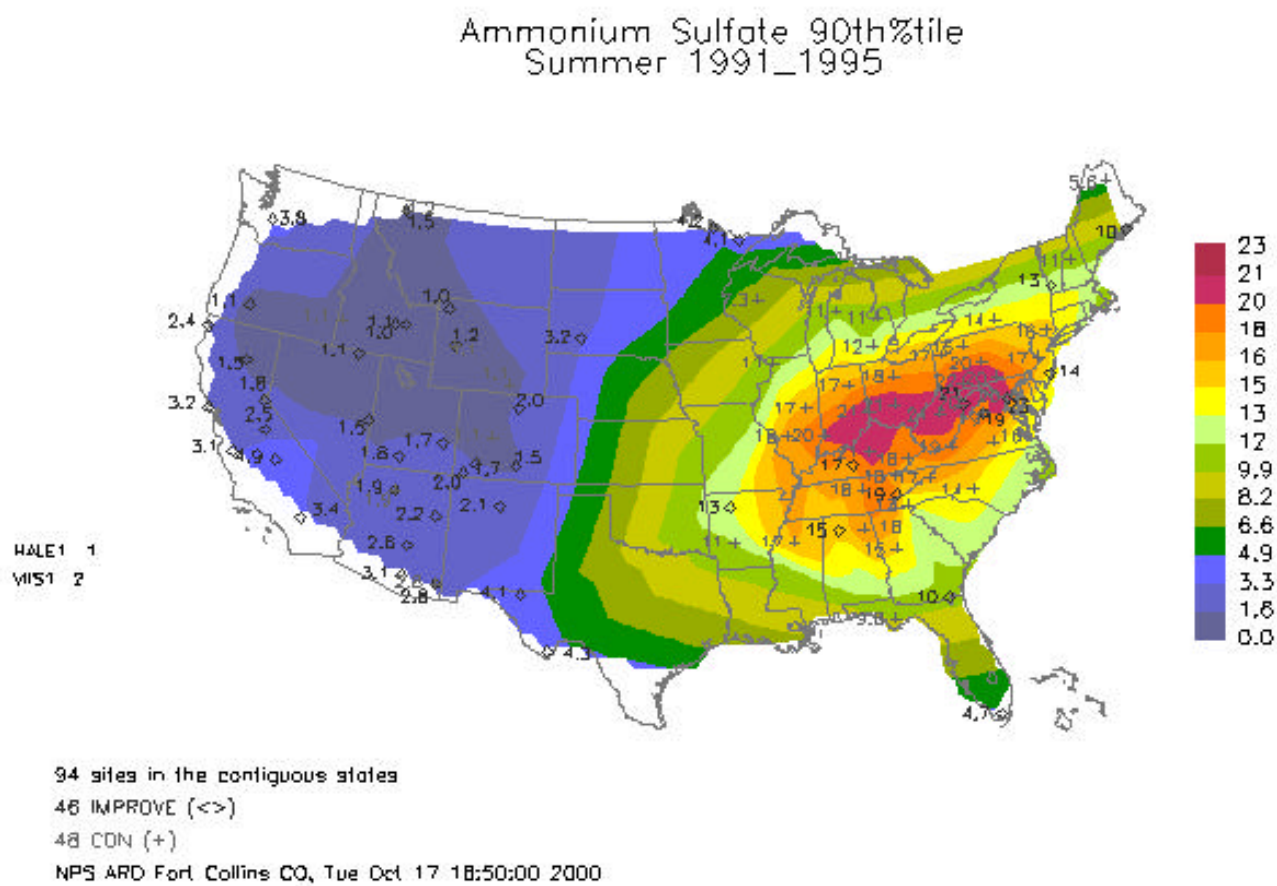
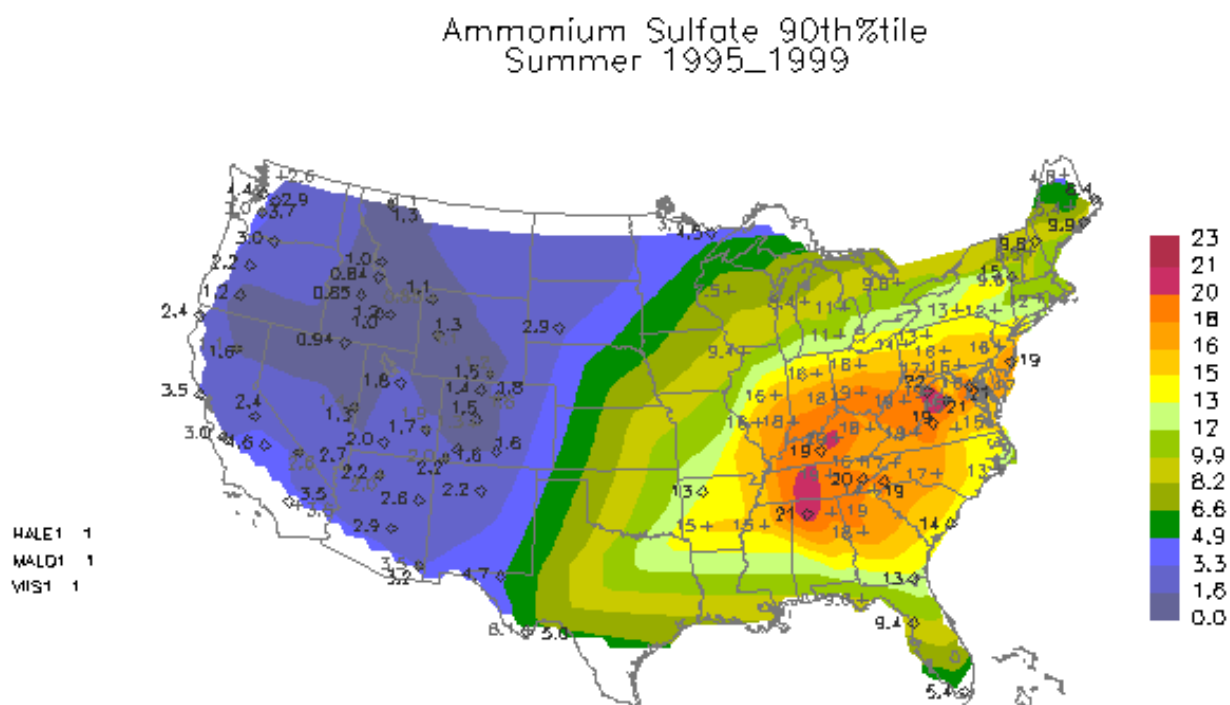




Figure 7b. High Summertime Ammonium Sulfate Concentrations ( $\mu\text{g}/\text{m}^3$ )  
1995-1999.



128 sites in the contiguous states

B1 IMPROVE (<=)

B7 CON (+)

NPS ARD Fort Collins CO, Tue Oct 17 18:50:08 2000

Figure 8a. High Wintertime Ammonium Nitrate Concentrations ( $\mu\text{g}/\text{m}^3$ )  
1991-1995.

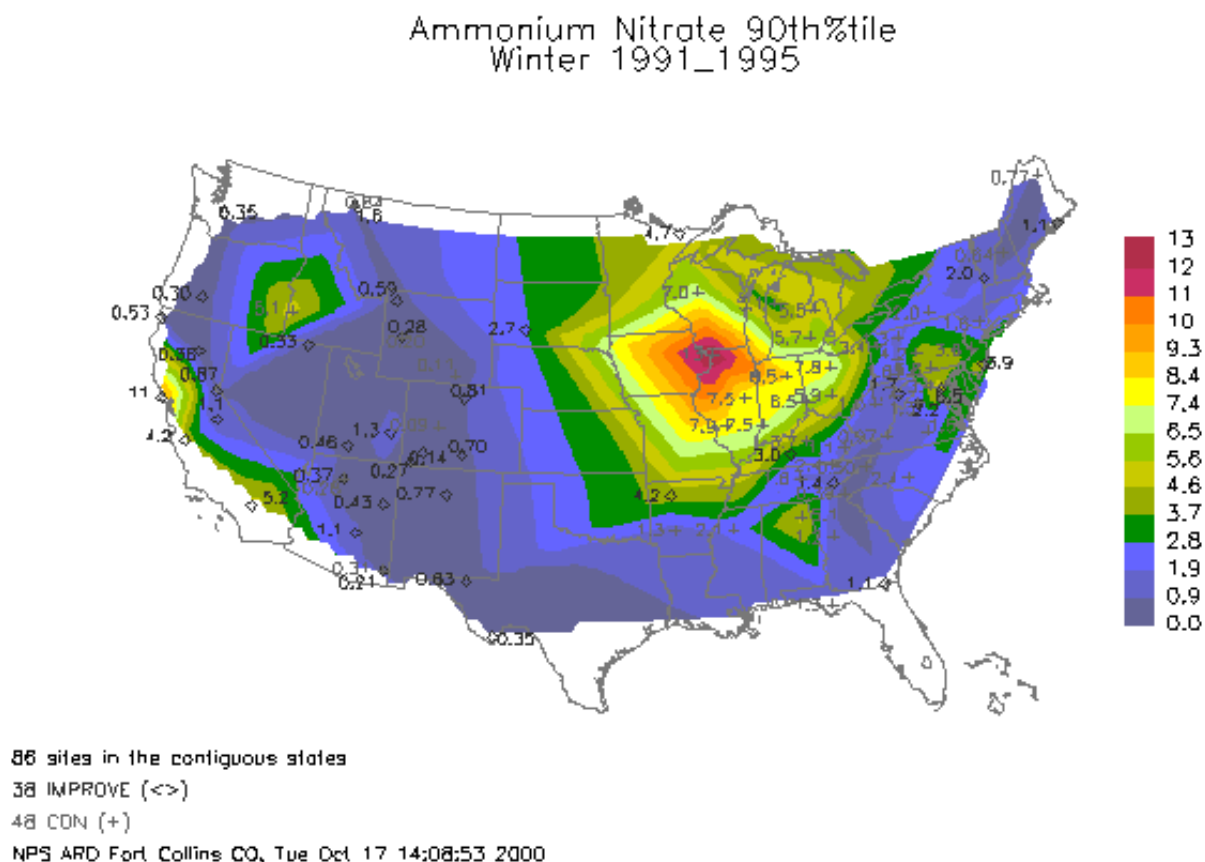
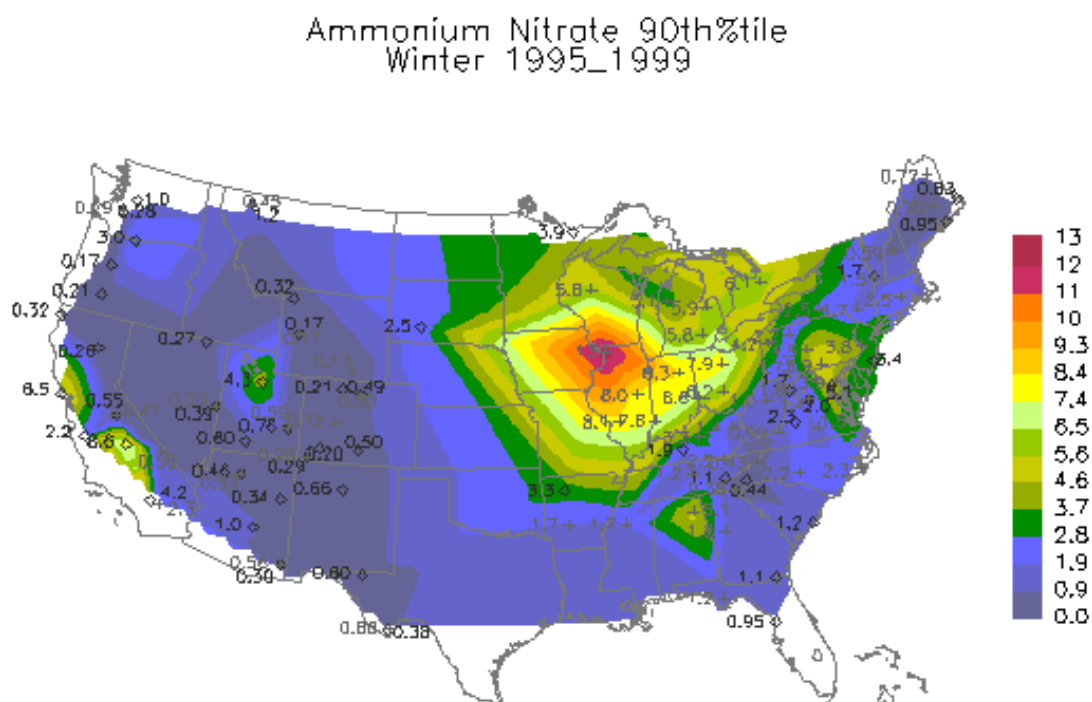


Figure 8b. High Wintertime Ammonium Nitrate Concentrations ( $\mu\text{g}/\text{m}^3$ )  
1995-1999.



111 sites in the contiguous states

49 IMPROVE (<>)

82 CDN (+)

NPS ARD Fort Collins CO, Tue Oct 17 14:09:01 2000

Figure 9a. Annual Reconstructed Fine Mass and Aerosol Extinction for Haziest Days at Shenandoah NP.

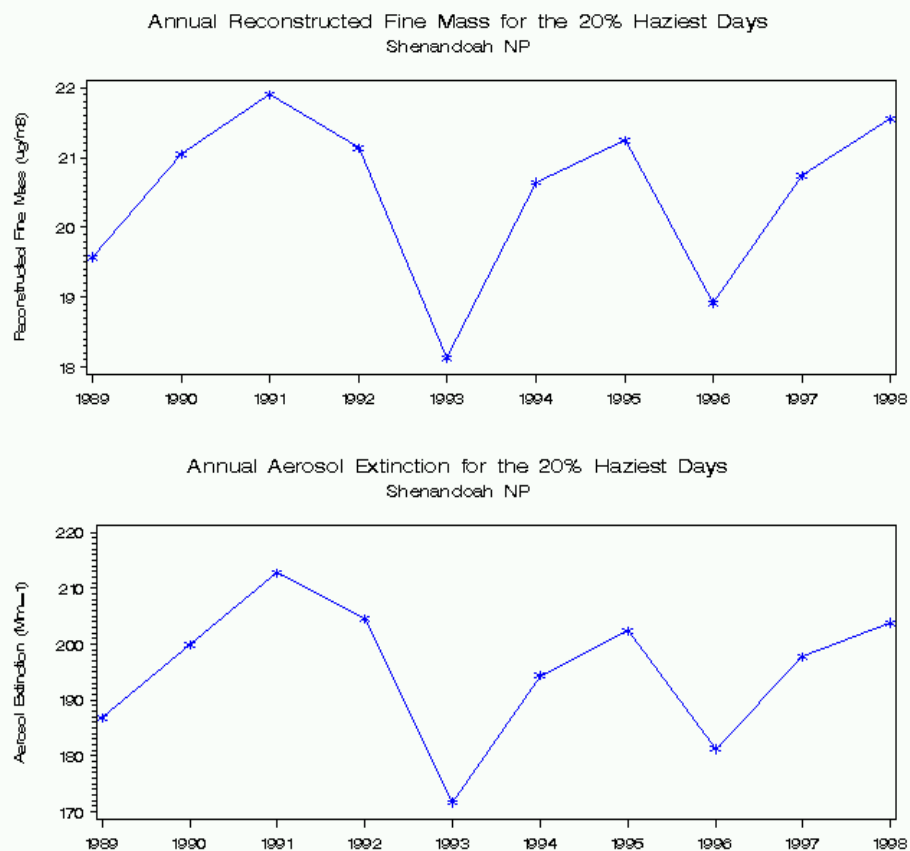


Figure 9b. Annual Reconstructed Fine Mass and Aerosol Extinction for Haziest Days at Great Smoky Mountain NP.

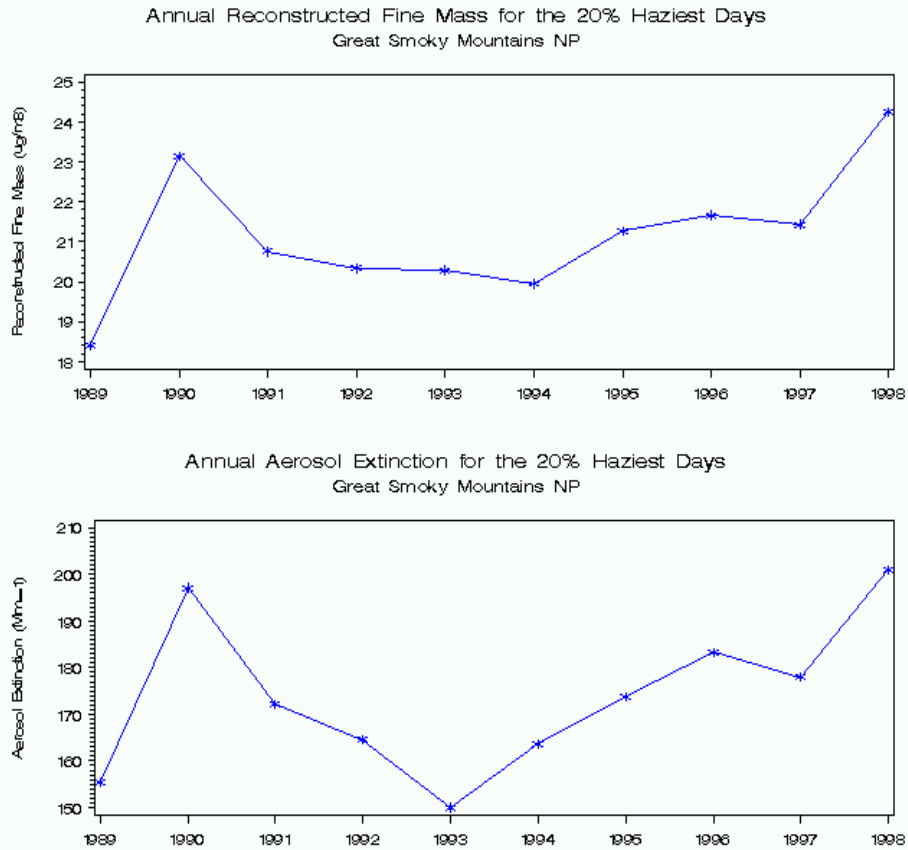


Figure 9c. Annual Reconstructed Fine Mass and Aerosol Extinction for Haziest Days at Rocky Mountain NP.

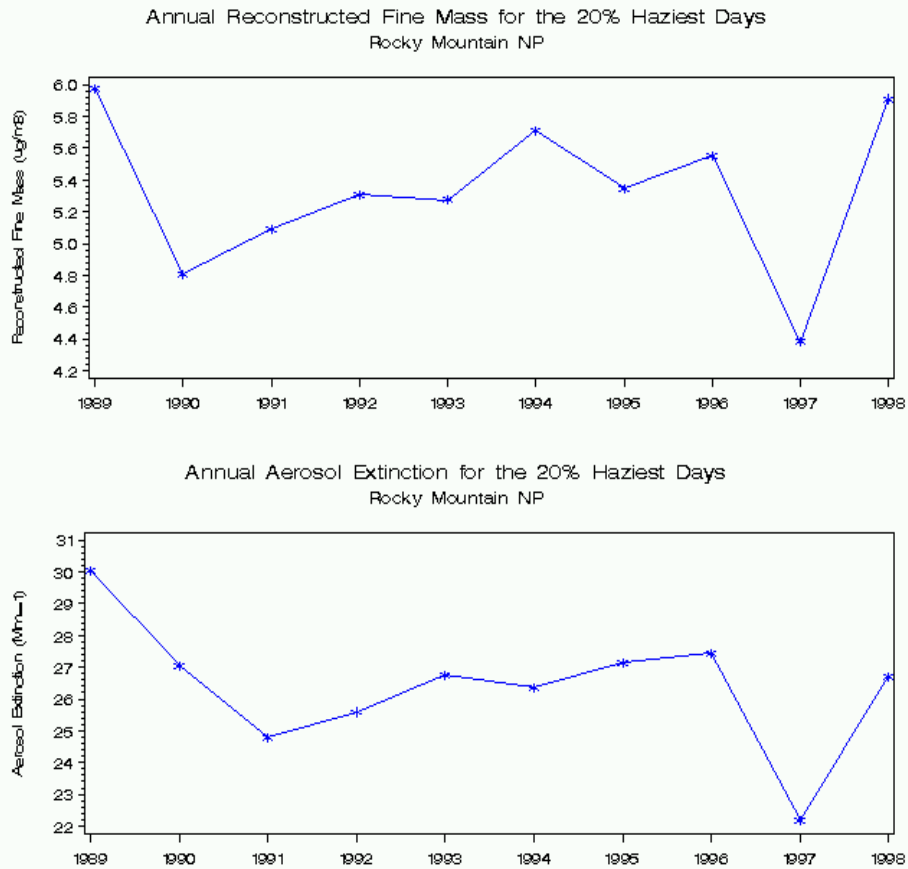


Figure 9d. Annual Reconstructed Fine Mass and Aerosol Extinction for Haziest Days at Brigantine W.

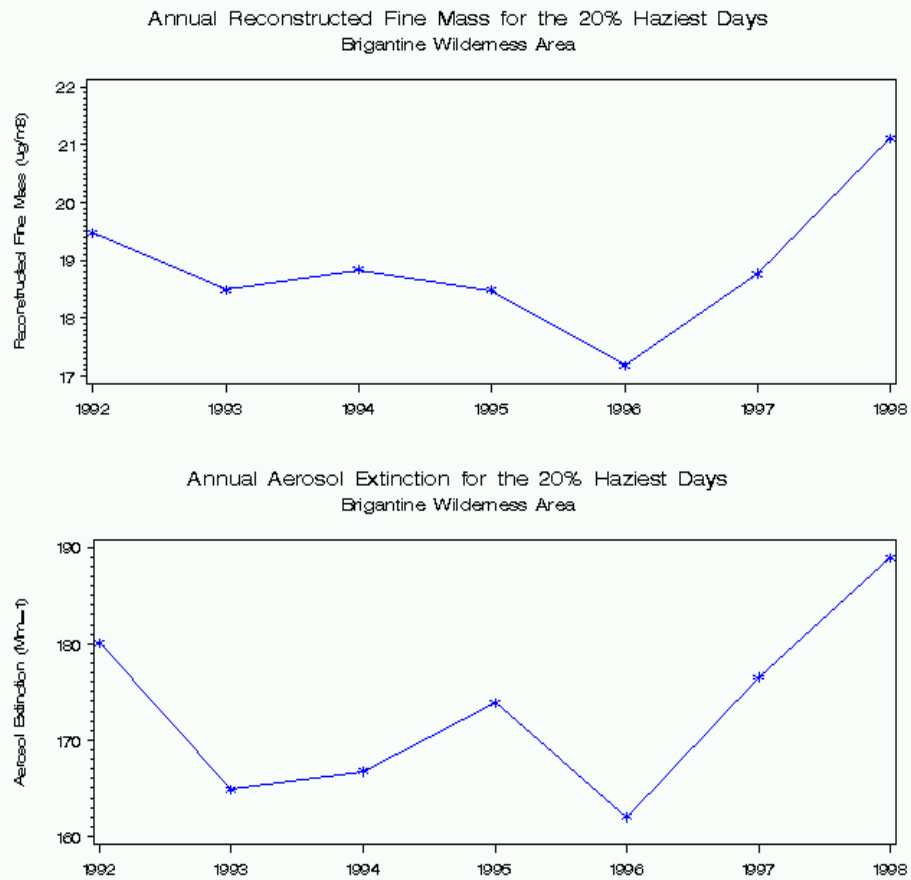


Figure 10. Trends in Sulfate Mass Concentration on the 20% Worst Days (1989-1999)

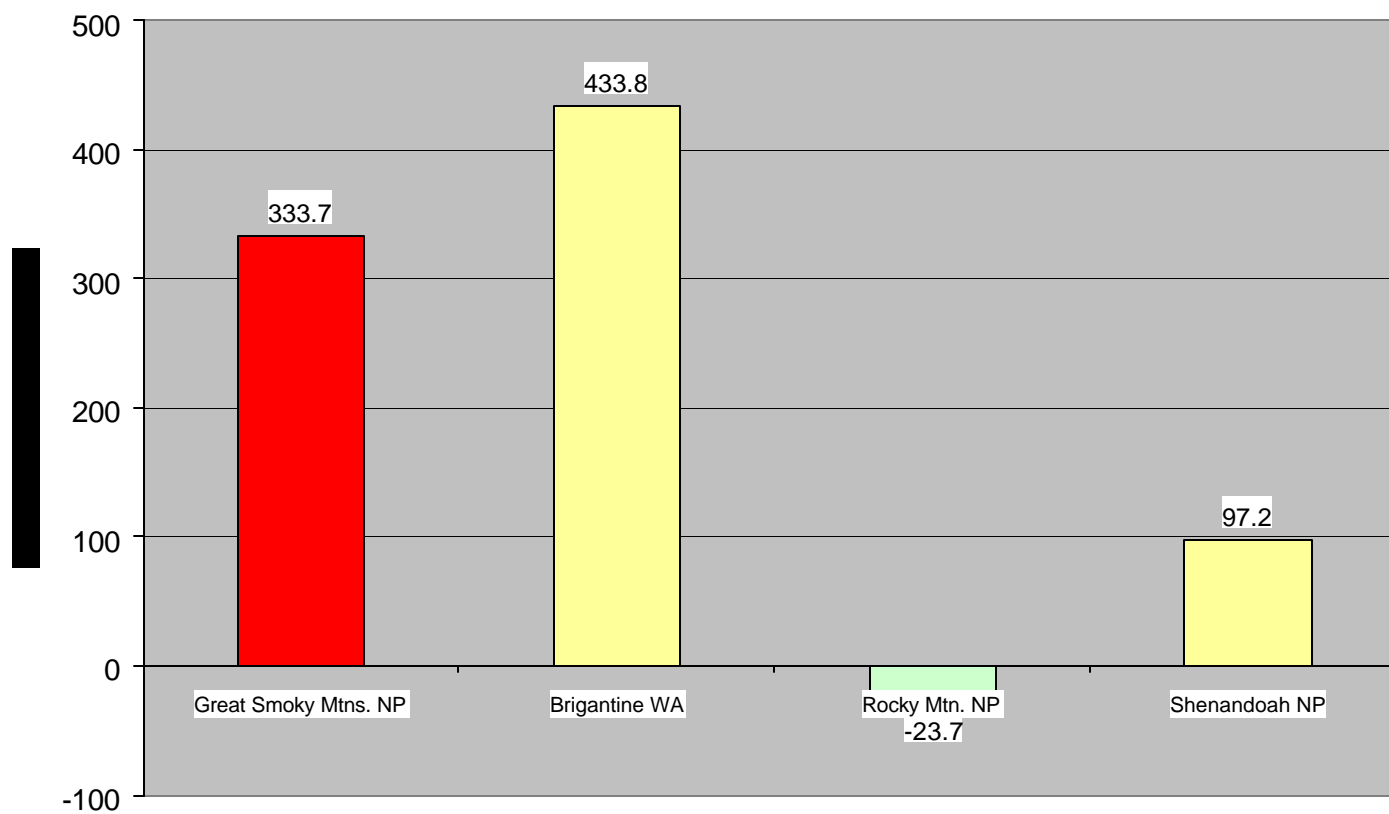




Figure 11a. Shenandoah High Extinction Conditional Probability

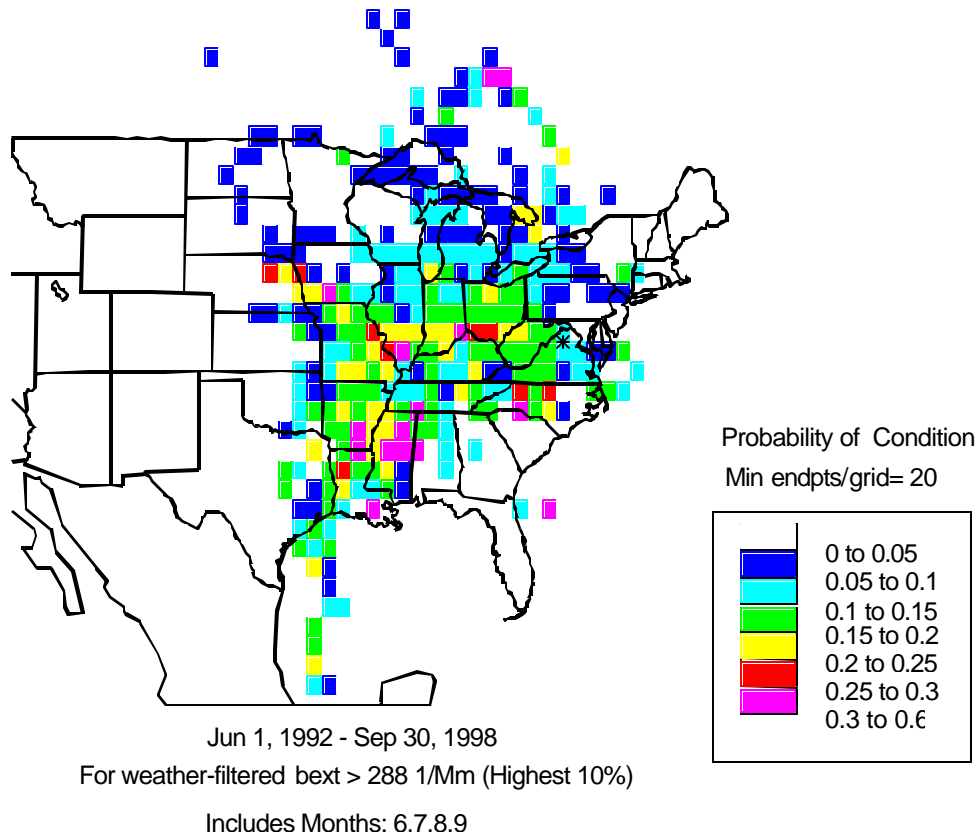


Figure 11b. Great Smoky Mts. High Particle Scattering Conditional Probability

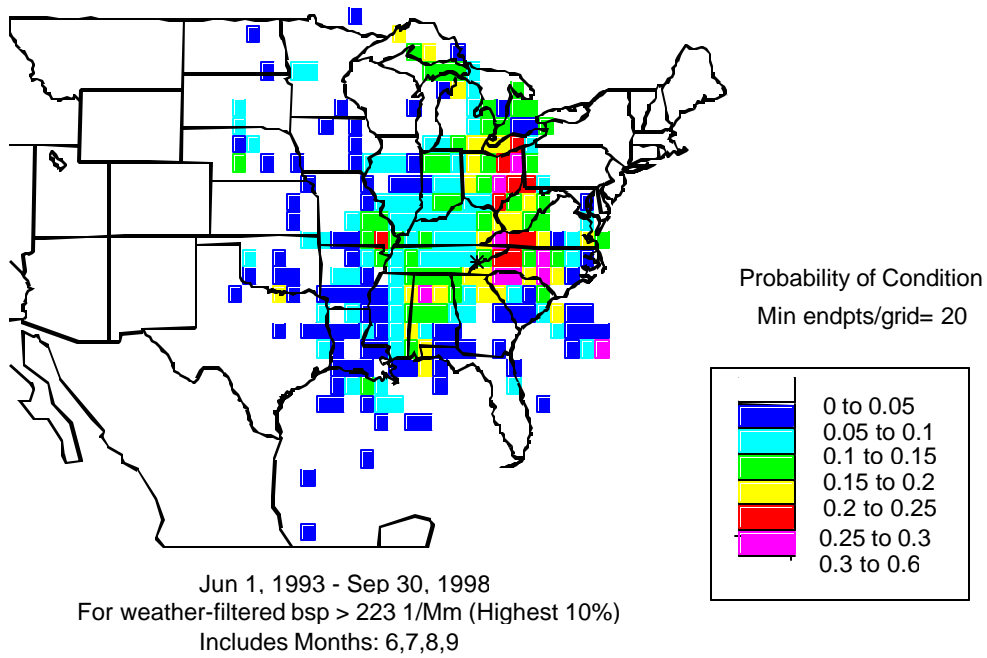


Figure 11c. Rocky Mountain High Extinction Conditional Probability.

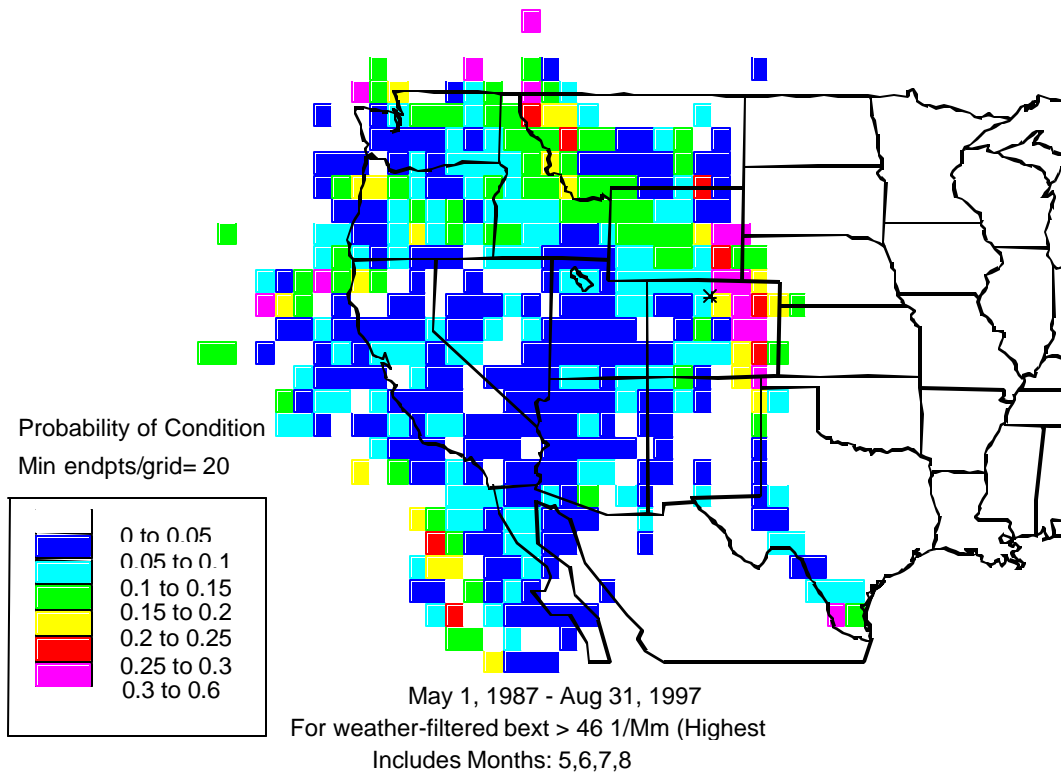


Figure 12a. Shenandoah High Extinction Source Contribution

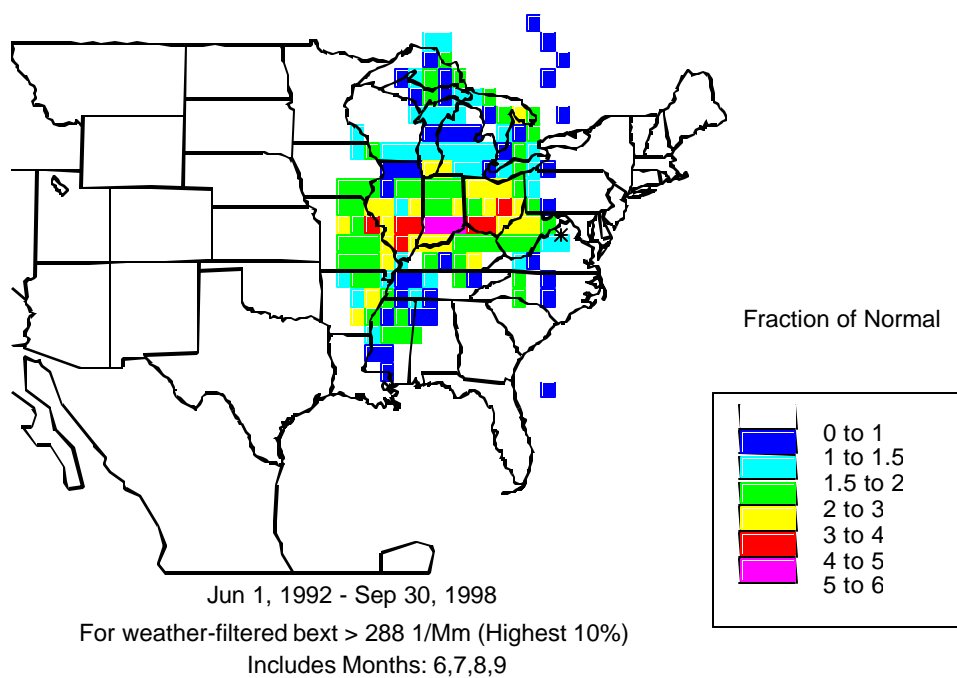


Figure 12b. Great Smoky Mountains High Particle Scattering Source Contribution.

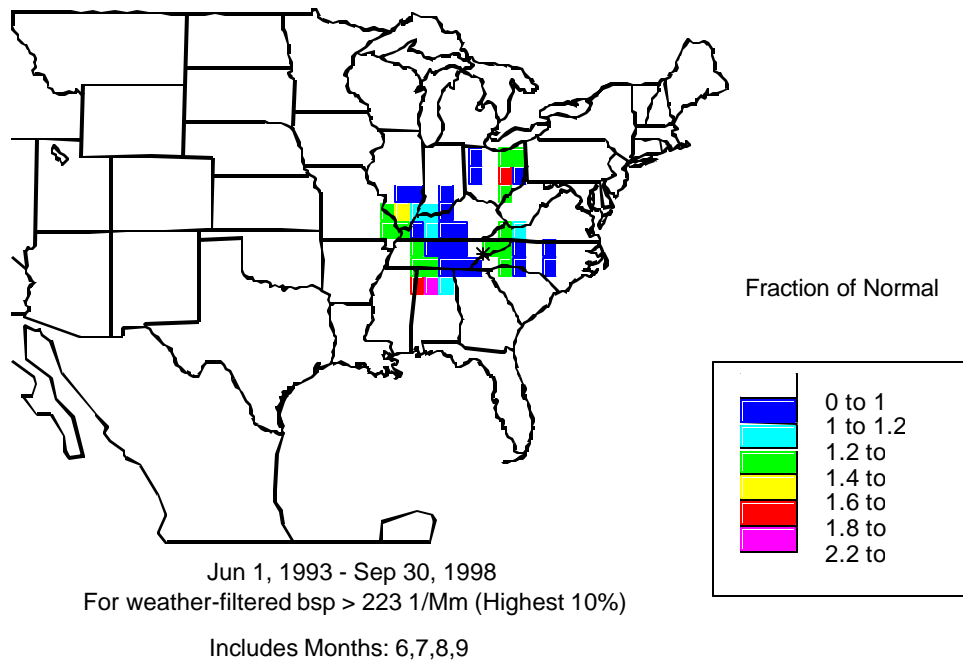


Figure 12c. Rocky Mountain High Extinction Source Contribution.

